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The Development of a Multifunctional Antenna Precursor for Ground Vehicle Structures

by Shawn M. Walsh, Gregory Teitelbaum, John Cook, Alvin Lim, and Kirk Tackitt

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14. ABSTRACT

U.S. Army transformation will require lighter, more rapidly deployable ground vehicle systems. Equally important will be the need for superior communication and sensor capability to detect and respond to friendly and hostile entities. The challenge is to consolidate the required armor, infrastructure, electronic hardware, and other systems into a lightweight vehicle structure. This particular research provides a very preliminary but nevertheless representative effort to explore conformal and multifunctional material systems with the primary goal of reducing weight and volume. A typical structural armor is used as the starting point, and a metallic antenna element is integrated into the structure. Preliminary results are presented, and the intent is to use these results to identify issues, constraints, advantages/disadvantages, and to evolve toward a truly multifunctional solution wherein "atoms are shared" in more than one required function (e.g., armor, structure, electromagnetic radiation of modulated signals).

15. SUBJECT TERMS

antenna; multi-functional materials; structural antenna; structural composites

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1. Introduction

Continuing efforts to reduce the overall weight of U.S. Army systems while maintaining and/or increasing functionality have led to the need of innovative and efficient methods that can be employed to meet new demands. The U.S. Army's Future Combat Systems (FCS) will require systems to weigh 16 to 20 tons while still being fully armed, armored, and operational. The integration of multiple components of these systems may allow for rigorous FCS weight requirements to be met while sustaining a full level of serviceability. In parallel with this concept, the integration of a communications antenna into the armor of a vehicle (figure 1[1]) may be an efficient approach to minimizing space and weight without sacrificing the characteristics of either subsystem.

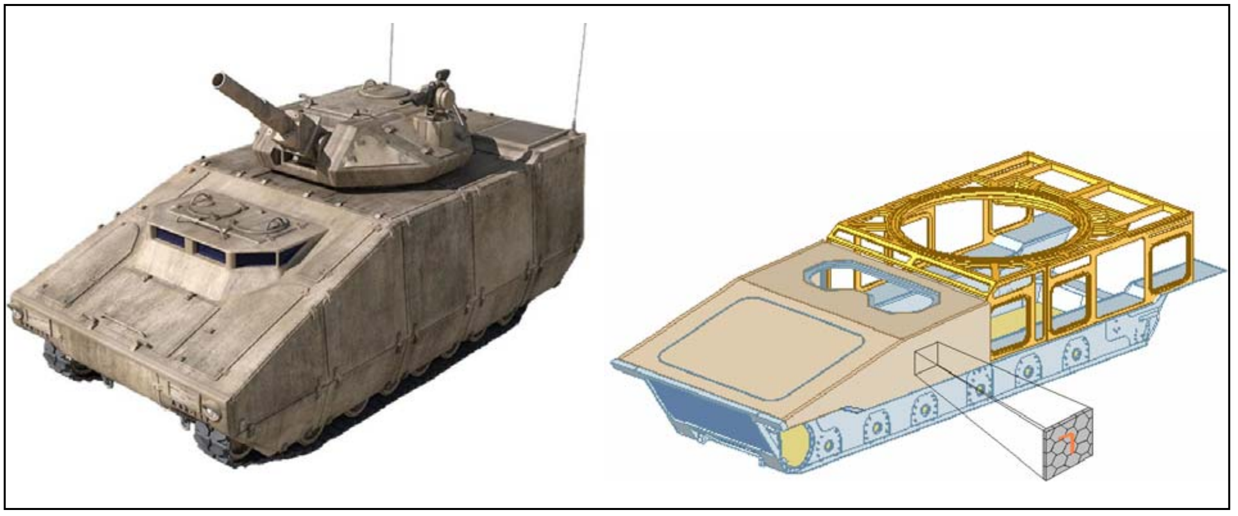

Figure 1. A conceptual FCS vehicle with embedded antenna armor.

2. Background

Development of a structurally embedded antenna involves the combination two previously separate fields of study: communications systems and structural armor. These issues fall under two categories of research. One concern is the ability to maintain performance levels of the armor after integration of the antenna (*1*,*2*,*3*,*4*). Research and development concerning embedded antenna structures, primarily in the aerospace industry, have traditionally relied on

[1]The source of figure 1 was a manufacturing technology objective briefing on Future Combat Systems in March 2005.

composite sandwich structures. The materials in these preliminary structures have included S2[2] glass-epoxy panels, aluminum honeycomb structures, and more recently, graphite skins. These materials have been previously chosen over other combinations such as Kevlar[3] 49-epoxy because they have higher dielectric constant and tangent loss that limit the performance of the embedded antenna. The ability to maintain structural requirements while allowing effective transmission of signal has dictated the choice of materials so far in this area of research.

Another focus of research in the field of embedded antennas is the design and implementation of the antenna itself. Typically, designs have relied on a single-ply antenna layer that has a two-dimensional geometry. In some cases, a dielectric layer was used to have the antenna itself to perform on the level of antennas many times larger. Radio frequency (RF) absorbers have also been implemented in early prototypical designs. Once the antenna assembly has been designed, it must be determined how to "feed" it with an RF signal. Most preliminary designs have allowed for a feed cone or feed lines to distribute the signal. The combination and integration of a highly capable structure and a fully functioning antenna are the ultimate goal in developing and prototyping a structurally embedded antenna.

3. Prototyping Embedded Antenna

To show the feasibility of a communications antenna embedded into vehicle armor, an armor "recipe" currently prototyped at the U.S. Army Research Laboratory was chosen to occupy the antenna. This recipe consisted of glass fibers (one panel using S2 glass and the other using E-glass) infused with an SC-15 resin along with a tile array composed of 0.75-inch hexagonal ceramic tiles. The prototype then consists of an antenna manufactured from thin copper sheeting that is embedded on either side of the tile array. The choice of this armor recipe allowed for an easy fabrication (because of our familiarity with the process) and showed that the antenna could be placed into an armor system with minimal changes in the recipe of the panel.

The fabrication of the armor panel with embedded antenna began with the construction of a 0.75-inch thick glass panel to act as a backing plate and frame for the tile array and antenna. Thirty-two plies of E-glass (30 inches by 30 inches) were then infused with an SC-15 resin via the vacuum-assisted resin transfer molding (VARTM) method. In this process, a composite pre-form is under vacuum, and resin at atmospheric pressure is pulled into the part until the fibers are completely infused (figure 2). After infusion and curing, this 0.75-inch thick panel was cut into a base plate of 20 inches by 20 inches and border panels consisting of two 20-inch by 2.5-inch and two 15-inch by 2.5-inch pieces. The border panels were then attached to the outside of the

[2]S2 glass was developed in the 1960s by Owens-Corning to bridge the gap between E-glass and mil-spec S-glass. Compared to E-glass, S-glass provides about 40% higher tensile and flexural strengths, about 10 to 20% higher compressive strength and flexural modulus, and greater abrasion resistance.

[3]Kevlar is a registered trademark of E. I. DuPont de Nemours and Co., Inc.

base plate with an E-120HP Hysol[4] epoxy. This frame would allow for the tile array to be placed inside. To allow connection access to the copper antenna, a hole was then drilled in the rear of the panel. To complete the frame, strips of Velcro[5] were placed on the edge of the panel so that a removable cover panel could be later attached. The final frame is shown in figure 3.

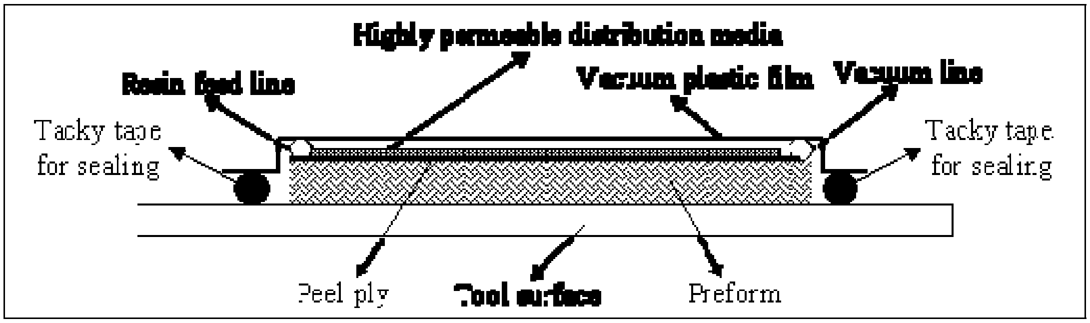

Figure 2. The VARTM process.

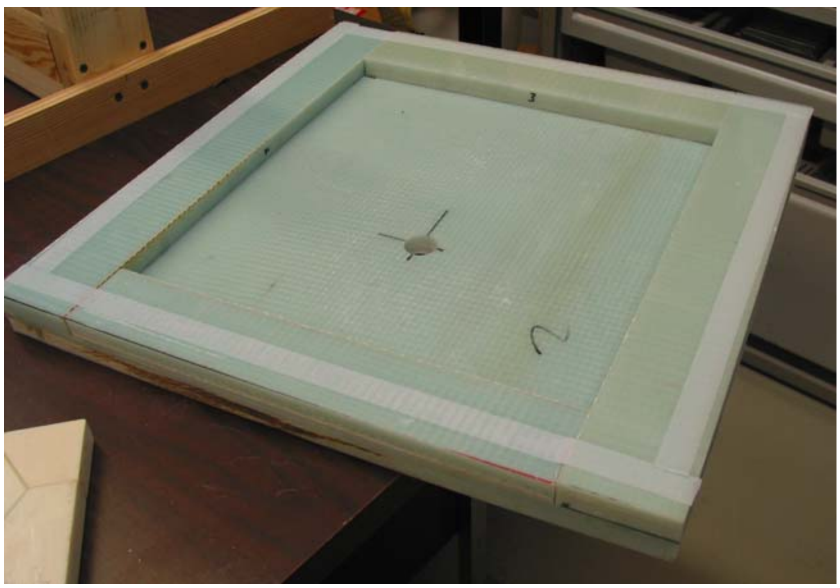

Figure 3. Fabricated E-glass frame for embedded antenna.

A tile array was constructed and instaled inside the E-glass frame. A 15-inch by 15-inch array of 0.75-inch-thick hexagon ceramic tiles was bonded with an E-120HP Hysol epoxy. This tile array fit into the previously constructed glass frame. A copper antenna was designed to be attached to the tile array (*5*). A geometry was chosen that consisted of a large ground plane on one side of the tile array and a smaller transmitting plane on the opposite side. The two sides of the copper

[4]Hysol is a registered trademark of Henkel Loctite Corporation.
[5]Velcro is a registered trademark of Velcro USA, Inc.

antenna were attached to the tile array with a 3M[6] Super 77 spray adhesive. The antenna designs can be seen in figure 4.

Figure 4. Copper antenna design.

To allow for a connection between the antenna and an electronic device, a BNC (Bayonet Neill-Concelman) connector was soldered to the ground plane of the antenna. This allowed a BNC cable to be connected to the antenna at one end and either a radio or oscilloscope at the opposite end. The hole drilled into the glass frame allowed for the BNC cable to run through the panel (figure 5). Figure 6 shows the completed tile array with the antenna attached along side the glass frame.

Figure 5. BNC connector accessible through rear of plate.

To allow for visibility of the tile array and antenna, a cover panel was fabricated to be attached over the glass frame. This was done by the VARTM method. The panel was composed of two

[6]3M and Super 77 are trademarks of the 3M Company.

20-inch by 20-inch plies of E-glass and was infused with SC-15 resin. After infusion and curing, Velcro was then placed the outer rim of the cover panel to allow it to be attached to the antenna frame (figure 7).

Figure 6. Tile array with embedded antenna and E-glass frame.

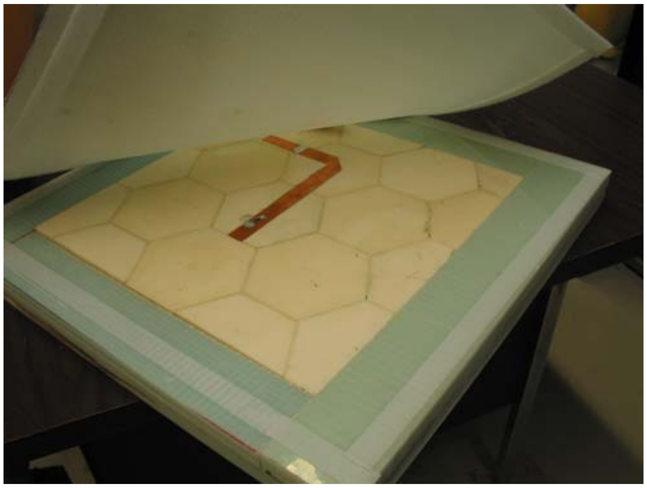

Figure 7. Tile array placed in E-glass frame with two-ply E-glass cover panel.

To enable the armor panels to be free standing, a wooden frame was constructed to house each armor panel. The frame was built to allow easy placement and removal of the panel from the frame, while allowing the BNC cable to pass through. The frame is shown in figure 8. After construction of the frame, the armor panels were completed and ready to be tested.

Figure 8. Panel in wooden frame with BNC cable connected.

4. Setup and Testing of Embedded Antenna

Once the antennas were embedded, it was necessary to test to see if the antennas could communicate with one another. To test their communicating ability, carrier wave strength was measured from a radio transmitting through an embedded antenna. An oscilloscope, which was connected to the other antenna, measured the change in intensity from the carrier wave as the transmitting radio was rapidly connected and disconnected from another embedded antenna.

The antenna systems were positioned about 70 feet away from each other with the transmitting planes facing each other. The radio was turned on and off rapidly for approximately 30 seconds. The data from the oscilloscope were recorded via a connected computer. This computer, using LabVIEW[7] software, recorded voltage data points every 0.1 millisecond. Following the test, these data were then plotted via Microsoft Excel[8]. The resulting graph is shown in figure 9.

[7]LabVIEW is a trademark of National Instruments Corp.
[8]Excel is a trademark of Microsoft.

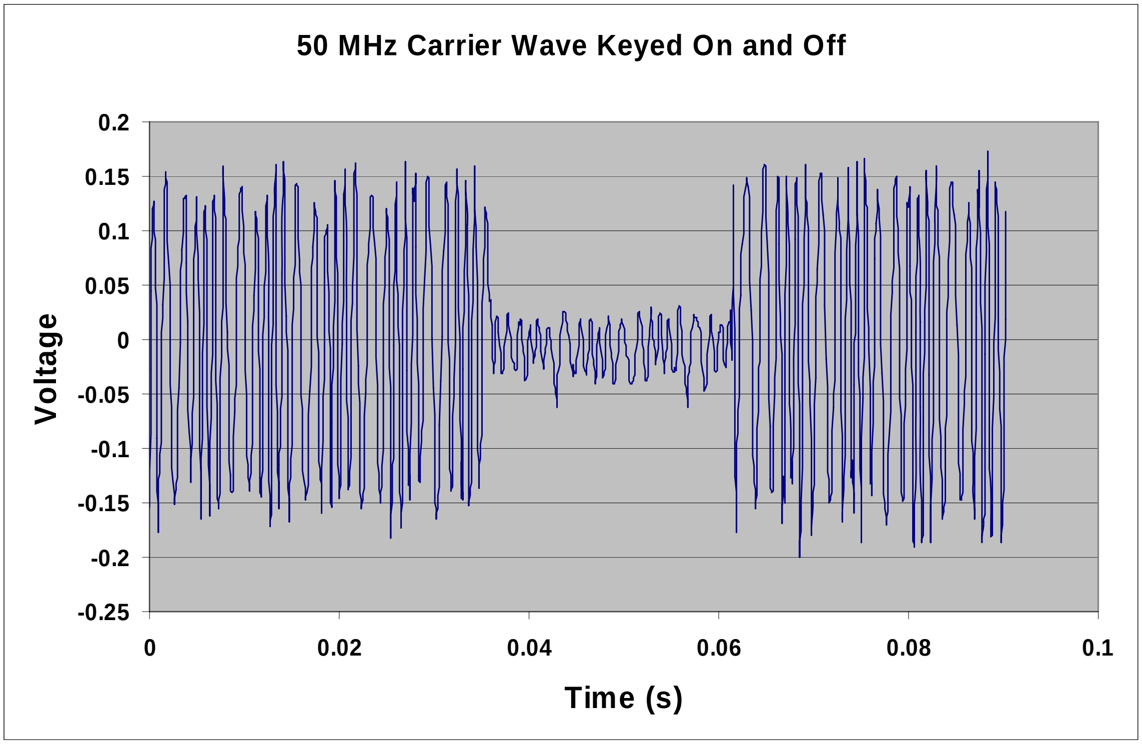

Figure 9. Graph of incoming carrier wave.

5. Results and Discussion

As can be seen from the preceding graph, it was instantly visible that the two embedded antennas possessed the capability of communicating with each other. A large difference in incoming voltage was detected as the carrier wave was turned on and off from the transmitting antenna. From this experiment, evidence in the form of tangible data was collected to support the feasibility of a communications system embedded into vehicle armor.

Because the research goal was to prototype the capability of such a communications system, we left room for optimization. A more in-depth analysis could have been used in researching the geometry of the antenna itself. This would have allowed for better transmission quality and range. However, the geometry used was sufficient in showing the feasibility of an integrated antenna, since a very visible change in the voltage of the carrier wave was seen as the antenna was rapidly turned on and off.

For further research, the effects that different fibers in the armor panel have on antenna performance may need to be examined. S2 and E-glass fibers were employed because of their common use in armor paneling, but different fibers may be able to increase transmission quality and range of the integrated antenna. The operating frequency of the item transmitting the signal through the antenna was also a variable that could be examined in future research. Different operating frequencies may provide better antenna performance without otherwise altering the design of the armor or the antenna.

6. Summary

A prototype has been developed that has integrated an embedded antenna into structural armor. Through common fabrication practices and designs, it has been shown that the integration of such an antenna into existing armor recipes can be done so feasibly and effectively. Although in its very early stages, this preliminary research has shown enough possibility to warrant a more in-depth study concerning the effects of changing such variables as antenna geometry and fiber selection. Through future examination and research, the potential applications of an embedded antenna structure will be determined and more advanced and specialized prototypes can be designed and fabricated. This work has allowed for an advance in the design of such structural armor and has addressed some issues that may need to be further examined. As important, this work identified the potential for a truly multifunctional approach in realizing the simultaneous properties required in such a system.

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